# THE MOTIONS OF THE HEART,

## THE CIRCULATION OF THE BLOOD, Etc.,

### VIEWED MORPHOLOGICALLY.

BY

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THERE is nothing in nature more wonderful than the persistent action of the heart. Beginning as a *punctum saliens* with the first development of the embryo, it never ceases, perhaps for a hundred years, completing a definite cycle of motions upwards of seventy times every minute, and that—not like the beam of a fine balance set on friction-wheels *in vacuo*, or any mechanism where the resistance is a minimum, but—in opposition to such resistance that, viewed as work, it has been estimated at the raising of a ton, or say fourteen men, from the bottom of a pit 120 (or say rather 43) feet deep in twenty-four hours![1] Nor is the action of the heart less important than it is wonderful. It is the indispensable condition of nutrition, nay, of bodily life; and in reference to all intense mental states or emotions and many other phenomena, it is to the whole frame what the action of the governor on the steam-pipe (which controls the supply of steam) is to the working of the steam-engine.

It is only to be expected, therefore, that ever since the discovery of the circulation of the blood the greatest physiologists should have

[1] A great diversity of opinion prevails as to the force which the heart puts forth. Professor Buchanan of Glasgow, whose views are very considerate, estimating it as a lift, gives 42·3 foot-tons in twenty-four hours. Professor Haughton of Dublin estimates it at more than double—viz., 89·7 foot-tons in the same time; while Professor Huxley of London, in his Table of Physiological Constants, gives it at 90 foot-tons for the left ventricle, and 120 foot-tons for the whole heart.

thought long and done all they could to explain it. And so they have. Still, however, it must be confessed that in the main the action of the heart remains a mystery to this day, except, of course, to those who are content to invoke on all occasions the aid of such conceptions, or no-conceptions, as "vitality," "stimulus," etc.,—terms which do indeed mask ignorance so well that they seem to explain everything, while in reality they explain nothing, but merely re-state phenomena in the technical terms proper to the science of nescience instead of plain English.

My object in this communication is not to attempt more than has been accomplished already by the ordinary method of investigation (which would be vain), but to give a view of the action of the heart with its attached vessels in the light of the hitherto little-studied science of morphology. For, from this point of view, it comes out that the well-known action of the heart and its ramifying and retiform vessels is that which is proper to them in virtue of their respective forms, as these forms are realized more or less successfully in actual tissues.

But here it will be legitimately asked, What does this mean? And to this I reply, that, as in physics it has been found of much avail for the advancement of science to partition the whole subject of mechanics or the scientific study of *masses* into two, namely, *kinematics*, or a doctrine of pure motion, and *dynamics*, or a doctrine of embodied motion; so in physiology and the scientific study of *molecules*, it is advantageous to partition the entire study into two—namely, *morphology*, or the scientific study of pure form, and *anatomy*, the study of realized form or actual structure.

It has hitherto, at least in modern times, been usual to attend only to the latter, or, at any rate, to regard form as merely the outside of structure, as merely the incidental resultant of structure. But it is here maintained that this order of study ought to be reversed; that structure, at least where it is that of a naturally individualized object, ought to be regarded as the realization of form antecedently conceived and provided for by the specific endowments of the material elements.

The claims of morphology, in order to be admitted, need only to be considered. Thus, that every phenomenon, in order to be a phenomenon, must take place, will not be disputed. Now, to take place, what is it but to demand or assume some space as its own? and what is this but to demand or assume a form? It is usual, indeed, to think and speak of motion as well as of form as if the two were physically separable. But, however it may be in the abstract, a moment's reflection will show that motion, considered as a physical phenomenon, is only an affection of form, and that there can be no motion while there is no form to move. The mechanician, before he can get on at all with his demonstrations, must assume at least his "physical point" or "particle." Now, no point or particle, nor anything whatever, can be conceived as

existing in space but as a form of some kind. Morphology, therefore, or the science of form, is implicated in all scientific studies; and since "form" is not only the most extensive but also the most distinct of conceptions, and is, moreover, that which touches most closely upon "idea," it is certainly most worthy of separate and primary consideration.

What, then, let us ask, without further preamble, are the principles of this new, or rather, indeed, of this very old, science? (Consult Plato.) Happily they may be all explained in a single law, and that none other than the familiar LAW OF SYMMETRY. By this is meant a mode of action proper to the material elements, in virtue of which any individualized group of them, any molecule or organism, ever tends to grow or to be developed as symmetrically as incident forces, etc., will permit. It involves the following phenomena:—

FIRST RESULT.—The form of culmination in all cases, the sphere; meaning by spherical the spherical superficies shell or cell; for this is nothing else than that form in which symmetry is a maximum, inasmuch as symmetry consists in similarity in the relationship of all the parts or particles constituting a form to some one plane or line, ultimately some one point within the form—a condition this which is most completely fulfilled in the case of the spherical superficies, since in it the relationship of all the points is not only similar, but all the same, to one and the same point within the form, namely, the centre.

All the symmetry which Nature displays in all her individualized creations is, according to this view, a nisus towards the construction of the cellular. And surely it should not be regarded as anything wonderful if it should be found to be so. For the hollow sphere being arch all round, is the strongest form under incidental forces which can be constructed, and is, therefore, the fittest form with which to build or in which to dwell. It is also the house or vessel of the largest capacity which can be constructed out of a given quantity of materials, and, therefore, that in which the largest quantity of anything that is valuable may be secluded from exposure to unfriendly agencies, such as cold, oxygen, etc. In a word, the spherical contour is that type of form which reason leads us to expect in nature, in which, as the admirable Hales says, in his Hæmostatics (very valuable to this day, though brought out nearly a hundred and fifty years ago), "the farther we go the more we see the signatures of God's wisdom and power; everything pleases and instructs us, because in everything we see a wise design."

If it be asked how it is, if the cellular be really the choice of Nature, that she so seldom succeeds in her aim, since natural objects possessing a spherical form are but rare, the answer is, that they are rare only where incident forces absolutely prevent their construction. Among the particular objects on the surface of a planet, for instance, they are rare, because there gravitation, on the one hand, always pulling every part and particle towards the centre of the earth, tends to lay all forms flat; and the sunbeam and earth-cur-

rents, on the other hand, tend to draw them right up, or in some one line along. Thus, on the surface of a planet, what we are generally to expect under the law of sphericity, are either what may be ealled equatorial, laminar, frondaceous, forms; or else axial, prismatic, linear, forms; or both together, that is, such forms as have an axis and an equator only; or a combination of these two, consisting of equatorial elements radiating from an axis.

Now, not to stop here in order to show to what an extent systematic natural history may be assisted by a due regard to such leading ideas as to form, let us hasten to remark, that wherever gravitation, solar radiation, and incident forces in general are neutralized, the sphere is seen to rule. Thus, the disturbing influence of gravitation is obviously neutralized when the centre of gravity is also the centre of form. Now, this is the case with the heavenly bodies; and it is never doubted with respect to all of them, the millions upon millions of them, which exist, and indeed constitute the universe, that they are spherical externally at least, and most probably internally also. Again, gravitation is neutralized, at least nearly, in the case of small structures when holding place in a liquid of nearly the same specific gravity as themselves, as, for instance, in organic elements concreting in the plastic fluid of which they are constructed. Now, in reference to these also when most perfect, it has been found universally, both in reference to plants and animals, that at first they are all hollow spheres or cells; while multitudes of globules, spherules and spheres, spores, seeds, etc. etc., with contents more or less dissimilar to their walls, everywhere abound throughout the whole mineral, vegetable, and animal kingdoms. Such, then, is the first principle of that morphology, of which anatomy generally, or the science of structure, is the realization in matter; and it implies a second principle, which may also be stated, viz.:—

Second Result.—The activity proper to any form, great, in proportion as that form is non-symmetrical and non-spherical. This follows from the theory that the sphere is the limit of the action which aims at the perfection of individualized form, or the form of repose. But here it must be remarked that this repose proper to the spherical, is repose only with regard to the process of construction. When the cosmical law of assimilation[1] has been fulfilled, and the spherical in form attained, the material elements constituting that sphere are then in a situation each to assert its own right to its own individualized existence. Therefore:—

Third Result.—The solution of the cell and the attainment of the liquid or the aeriform state by its constituent elements. It would not do to enlarge here so as fully to explain and vindicate this assertion, but it is necessary to state it, because herein is the secret of secretion, as also of structural change and life generally.

[1] For the origin of this law, its cosmical character, and its sufficiency to explain phenomena without postulating any other, see "A Sketch of a Philosophy," by the Author (*passim*). 1868–1870. Williams and Norgate.

But to proceed. The sphere, then, being the type or ideal of an individualized form in reference to a mechanical system, such as that of the material creation, and these being the principles involved in this theory as to the type of form in nature, we are, in such a hypothesis, not only in possession of a principle to guide our systematic arrangements in natural history, but we are able to propose and solve many problems having most interesting bearings on anatomy and physiology. Thus, we may propose the problem, "to construct out of a suitable plastic fluid a vessel which shall act like a force-pump that works itself, and shall propel the remainder of the plastic fluid through the organism as long as possible." Nor can we merely propose this problem, which is plainly that of a heart. Our morphology enables us also to solve it. And to this let us now proceed. In practical mechanics the most analogous problem and its solution is perhaps the hydraulic ram—a most ingenious and beautiful apparatus for raising water by its own pressure to a higher level than its fountain,—which, however, unhappily, does not require a stethoscope to render audible the noise it makes, else it would doubtless be much more generally used than it is.

First, then, since this organism which we propose to construct is to work itself, and since no work is possible without dissipation of energy from the machine at work, our organism, since it cannot stand altogether alone, must be put in the way of obtaining a supply of energy from some other source as fast as it parts with its own. Now, this is secured for every part of the organization of an animal by the arrangement that the air, which is the great terrestrial storehouse of the energy of nature, is dovetailed into the animal, and made to give up its energy to the animal by continually renewed supplies of combustible matter (food), which are thrown in upon the air when within the animal, as coals are into the steam-engine, developing within the organism—not indeed a tissue of elastic vapour, first to fill the boiler, and then to be duly ramified through the engine, but—a tissue slightly concrete (in which also hydrogen plays an important part), first to fill the skull, and then to be duly ramified through the entire organization. In a word, in virtue of the connexion of the organism with the air and food, that organism is made to be (specially in the nervous system) a store of energy—such a store as tends, as often as it is emptied by work, to be replenished anew by the ambient energy of the universe. The first condition, then, is satisfied.

The second is, that the proposed vessel or chamber which is to act as a force-pump upon the remainder of the plastic fluid out of which it has been itself constructed shall (1) possess a *non-spherical*, as, for instance, a pyramidal or conical or hemiform shape; and (2) be so organized as to its muscular fibres and their fulcra, etc., that it shall be with respect to the plastic fluid contained in it as if it were itself plastic. These conditions fulfilled, it will, under the law of symmetry, which ever acts in the interest of sphericity,

as soon as its non-spherical form has been fully pronounced by the completed inflow of the plastic fluid, tend to make a movement towards its own sphericity. Now this must imply the diminution of its wall or *enceinte;* for the sphere is the smallest *enceinte* possible for a given quantity of fluid, and every movement from a less to a more spherical form of vessel implies a contraction of that vessel. *Thus we obtain a theory of systole.*

But although an organ composed of concrete materials may be constructed so that it may act in certain directions as if it were plastic, yet no such organ can be really plastic or in itself indifferent to form. It cannot but have a specific form—a form proper to itself considered as in a state of intimate equilibrium or repose. This we have indeed already postulated on assuming an organism to possess as its own a non-spherical form. Now this being so, it follows that as soon as it has expelled the plastic fluid which expanded and fully exposed its non-spherical form, it will resume its constitutional or specific form, non-spherical though it be. *Thus we have a theory of diastole.* And thus, without taking into account any ulterior organization framed to facilitate and sustain such a mode of action, an organ such as has been conceived will, as long as life remains to it, go on accomplishing systole and diastole. And indeed it has been found that the heart of a vertebrate, even after it has been cut out of the body of the animal, provided it be kept in possession of its own moisture and temperature, will continue to beat for days.

But to proceed. If, now, at that orifice in the expanding and contracting vessel by which the plastic fluid enters, a valve or some equivalent apparatus be applied to prevent regurgitation, and there be an opening for the exit of the fluid otherwise, and if to this opening there be a pipe attached which bends round and returns into the ventricular vessel again, then there may, as a consequence of the sustained systole and diastole of the vessel or ventricle, be a circulation for which the same quantity of fluid may possibly serve.

But such a circulation would serve no purpose. What is wanted is not merely a circulation, but such a circulation as will supply fresh material all through the body to take the place of that which is constantly being rendered useless by the spontaneous solution of cells and the breaking down of muscular elements which have done their work, and so have lost their self-sustaining energy. What is wanted, then, is not one circular vessel or tube merely with impervious walls, but an infinite number of tubes diffused all through the body, and ultimately more or less pervious. Hence, plainly, the tube issuing from the propulsive organ must be ramified to the utmost, and, as we shall presently see, formed if possible all through the organization into a universally distributed retiform plexus. Moreover, along with this, if what remains of the plastic fluid in the tubular vessels after having been thus distributed is to be brought back again to the ventricular organ, there must plainly also be a

system of vessels the very counterpart of what has been now described, the ends of its finest tubes inserted into those of the intermediate retiform tissue, proceeding parallel to the distributing tubes, and gradually gathered together into larger trunks until the ventricle is reached.

A vascular system, then, established in such a region as the body of an animal, having a central propulsive organ, ventricle or heart, and such that it may both irrigate the tissues of the animal generally and return what of the plastic fluid is not spent in this way to the heart—that is, circulate its contents—must consist of vessels which, except in the remote region which lies between those portions which propel from the heart and those which return to the heart, are *tapering or conical* tubes. Call them arteries and veins, or by any other name, they must be tapering or conical. But in being such they fall, when morphologically considered, under the same category as the ventricle or heart itself. In all animals they may indeed succeed in effecting a radiating mode of ramification, and the geometrical form circumscribing the aggregate of their tips may in some animals define a spherical superficies. But any single tube must be conical; and, if conical, then dissymmetrical; and hence, if organized in accordance with the law of symmetry and sphericity, it also will tend to act like a heart. It will tend to have its contraction of its wider part and its dilatation of its narrower part so as by action to form, as far as possible, the cylindrical or symmetrical in that which by structure is conical or non-symmetrical. Now, such a mode of action, if it be alternate in successive "reaches" of the vessel, or in the whole vessel, being a repetition of the action of the heart accommodated to the organism in which it has been embodied, must similarly tend to propel the plastic fluid within it. But in which direction? From its larger to its smaller diameter, or from its smaller to its larger? To this the answer is, that, considered simply as a conical vessel, it must tend to propel it in the direction in which the force is applied—that is, in this case, in the direetion in which the fluid is introduced. Suppose, then, that by the systole of the heart a just measure and no more of the plastic fluid is thrown into the conical vessel where it is in most immediate connexion with the heart, the effect must be a contraction immediately after of the vascular system nearer the heart, and its dilatation in the further region, the latter part taking place synchronously with the diastole of the heart itself. In this way the plastic fluid, notwithstanding an inevitable resistance to its current in a ramifying vascular system, may be successfully delivered with every pulsation of the heart into the more remote ramifications, and into the extreme network, where diffusion into the tissues is to take place. Not that it is to be expected that every beat of the central organ will still be marked there. This would only be if the whole vascular system were constructed of a rigid material: if it be constructed of an elastic material (which it is), then in the

extreme vessels the flow must tend to be uniform and equable, like that from the delivery-pipe in the hydraulic ram or a fire-engine.

Now, it will not be denied that the organization of the arteries is in perfect accordance with these morphological views. Thus, they are not merely elastic tubes capable of contraction and dilatation without injury, but they are elaborately muscular; the muscular fibres being disposed precisely to effect the action which has been described as proper to them, considered as conical forms into which fluid is sent from the larger to the lesser calibre.

As to the reciprocal system of vessels, the veins namely, the plastic fluid or moving force being applied in them at the opposite end, that is their narrow ends, the tendency to the symmetrical or the cylindrical will manifest itself by an opposite rhythm; that is, first a dilatation, which will, of course, be followed by a contraction. They will thus tend to propel the plastic fluid to the wider or more empty part, and so on towards the central organ or heart.

Further; in this view it is implied that there is a dilated state in the tips both of arteries and veins simultaneously. The mode of action is therefore most favourable for the utilizing of the capillary network lying between both for delivering up nutritious particles, and for conveying away such as have been used and are effete.

Moreover, this dilatation of the extreme branchlets or peripheral vessels may be expected to be simultaneous with the systole of the central organ. It will be perceived, therefore, how beautifully the action of each is calculated to sustain that of the other.

But such return of fluid by the veins, in so far as it depends on the mere form of the vessels, cannot but be imperfect. Even in the most favourable situation and circumstances—as, for instance, in utero—stagnation, nay a tendency to regurgitation, and, consequently, to a breaking-up of the current into eddies, or internodes and nodes, may be expected. But if so, then it may also be expected that the plastic fluid at the nodes will be concreted, and so form curtains or valves, loose or open in the direction in which the plastic fluid is, though with difficulty, forced to flow—valves thus calculated to prevent regurgitation.

Thus, what morphology leads us to look for in a conical vessel appointed to be the canal of the plastic fluid, out of which it is itself formed, is (1) when the course of that fluid is from the wider to the narrower end, a system of circular muscular elements provided to assist in establishing the symmetrical (the cylindrical) as the only possible approach to the spherical; and (2) when the flow of that fluid is from the narrower to the wider end, a system of septa (or valves), as the only possible attempt to divide this volume of fluid into spherical portions. And such is the theory of segmentation, partitionment, septa, etc., generally.

Upon the whole, then, it appears that, morphologically considered, the return of the plastic fluid by the veins must be as difficult as its diffusion and radiation by the arteries must be easy.

But here there presents itself one of these harmonies with which all nature is pregnant, and which demonstrates so completely one All-seeing Eye as the author of all. The absence in the veins of a powerful elastic tissue fortified by muscular elements, such as exists in the arteries, leaves their extreme branchlets so lax and thin as to be pervious to the fluid on the outside. Hence a powerful endosmose into them, and, consequently, along with a new supply of fluid to replace what has been given out for nutrition, *a vis a tergo*, helping the flow towards the heart.

Furthermore, let the venous system, after having been gathered together into a main, on entering the ventricle be dilated into an auricle, which is, like the ventricle itself, a non-symmetrical vessel, and the ventricle may be greatly assisted. In a word, as often as the plastic fluid coming in by this main has filled and developed the non-symmetry of this auricle, the latter will contract or accomplish a systole; and as this will be synchronous with the diastole of the ventricle, the plastic fluid, rather than encounter the fluid still returning by the main, will rush in and fill the ventricle. And if there be a pervious septum of a valvular structure between this terminal bulb of the venous system or auricle and the ventricle, to prevent the plastic fluid from returning into the auricle, the circulation may obviously be continuous and complete.

In the light of morphological law, then, we have to expect that the systole and the diastole of the central or auriculo-ventricular organ will be repeated or reflected functionally, though most probably invisibly to such eyes as ours (which are adjusted to enable us to lay hold of our food, not to discover the economy of the universe), in the extremities both of the arteries and of the veins, the systole at the centre corresponding to the diastole at the periphery. And hence an important result in diagnosis. The aspect of the surface shall normally represent or indicate the state or mode of the heart's action. It will tend to be too florid when the systole of the ventricle is overacting, too purply or wan when the ventricle is underacting or unable to balance the systole of the auricle (which must be the last to fail), and to empty it as completely as it fills.

Thus, also, we are able to understand how a natural injection of the peripheral tissue with arterial blood may, on the one hand, be quite transient and harmless, as in the case of anger or blushing (*i.e.*, anger at self), for it bespeaks the heart in a state of high action, while, on the other hand, the same colour may also be a symptom of a very bad state of things. There may, for instance, be a failure or loss of systole in the extremities of the arteries, local or more general, as there is in sphincters generally under paralysis; and similarly in the extremities of the veins. And then a peripheral injection may bespeak inflammation.

And now let us ask what is the use of all this apparatus and continued circulation of plastic fluid? That has not as yet appeared. But the answer is now imminent.

Between two systems of vessels, or, for simplicity of conception, say a system of two vessels, both of which are conical, and which are approached or applied to each other by their small ends, there must be a cylindrical portion. And this portion, being more symmetrical than either of the other two, will tend to be developed more and more as organization advances and culminates. Now, what will this be but a network of capillaries, such as has been frequently anticipated already, and such as actually exists?

And what, when morphologically considered, must be the action of this system of capillaries? This is easily answered: for they are cylindrical. And therefore, while fixed at the ends, they are already as symmetrical as it is possible for them to be. They will not therefore, in virtue of their form, tend to move the contained fluid either this way or that. As to the motion of fluid along their axis, it will be at the mercy of the conical vessels in connexion with them. But yet they will not be inactive. On the contrary, their action under the law of symmetry and sphericity must be most decided. In fact, viewed in reference to the sphere, each is merely an axis. Each is wholly in want of equatorially expanded matter. Hence each must tend, under the law of sphericity, to give out at right angles to its walls such parts or particles of the plastic fluid as can permeate these walls. In a word, the function of the capillaries must be to nourish the tissues which they traverse. Here, then, we see the use for which the circulating system exists; and here, therefore, let us bring our investigation to a close.

*P.S.—The Development of Glands.*—If there be a single capillary, or a pencil, or tuft of capillaries which is not soldered and fixed at both ends, as has been supposed in reference to the system of capillaries which lies between the venous and arterial systems, but is loose or free at one end, what, let us ask, will happen then? To this it is to be answered, that, under the law of sphericity, that capillary or these capillaries must tend first to become tortuous, and, ultimately, each to coil itself up into a ball like an earthworm in dry weather, a snake, or any animal with a long axis when it goes asleep. And thus, instead of an extended capillary we shall have a glomerulus. Now, many glands maintain permanently this structure, as in the mesentery, the lymphatics, Malpighian capsules of the kidney, testicles, etc. But the morphological action will not usually terminate here. A further action of the law of sphericity demands the solution of the tubular structure of the interior of the glomerulus. Thus the gland will yield a proper secretion; and on dissection it will present itself only as an utricle or follicle. Such gland-elements, therefore, viewed in reference to the whole of their functions, ought to be regarded as something more than merely the subjects of osmose. Their action, also, ought to be viewed as something more than a mere overflowing into their ducts when they are over full. Unless the follicle or utricle be perfectly spherical, which no glandular element having a

duct in connexion with it ever can be, it must tend more or less to a systole and diastole as stimuli dictate, so as to give its secretion not in a continuous current, but in floods and ebbs. And that such is the action of glands is well known.

*The Construction of a Heart.*—Given a tubular or cylindrical vessel, then, free or at least movable at one or both ends, we are now able to see how it may be developed into a heart, even into such a seemingly complicated heart as exists in the mammalia. Thus, under the law of sphericity, the given tube, instead of continuing extended, must tend to take a turn upon itself, trying, as it were, to form a knot upon itself and become spherical. But if meanwhile there be proceeding along its length currents from its opposite ends, these currents, when passing each other, will give nodal or non-moving plastic matter in the plane between them. And that nodal matter will tend, as in the veins, to concrete into a partition or septum which in this case will be longitudinal. And this, when the turn or quasi-knot on the vessel is symmetrically adjusted in two planes at right angles to each other, may give four valvular septa or partitions, lying across each other, as in the heart of a mammal—all which, observation of the successive stages of the construction of the fœtal heart verifies; which verification, however, I do not adduce, as indeed nothing of this kind, in this paper, generally, leaving verification wholly to the well-informed physiologist.

*The Morphological Cause of Muscular Action generally.*—The views advanced in this communication apply not only to the actions of the heart and the arteries, but to the action of muscles generally. Most muscles, indeed, differ from the heart and arteries in being symmetrical in form, which the heart and arteries are not; or at least in consisting of muscular fasciculi which are symmetrical. A muscle is most generally fusiform, or lengthened in form either as a whole or in the elements of which it consists. Now to such a form, considered as such, and free to alter from within itself, and alive, action is proper. Moreover, that action ought in every case, according to our theory, to be a movement in the interest of its sphericity, and consequently a shortening of its axis or length, and an enlargement of its equatorial or transverse section or belly—a contraction, in short—implying the approach to each other of its two ends, or of the points between which it is extended. Now, it will not be denied that this is the characteristic action of muscles generally, the state of repose being supposed to be that which the structure of the muscular tissue tends to re-establish, that is, the moderately extended state.

As to the immediate *physical* condition or cause which determines a muscular contraction, it is, according to our views, a development of heat in the muscle, that heat being required to meet the greater capacity for heat belonging to aqueous matter and ammonia when they assume their equatorially expanded or axially contracted forms (for they are both dimorphous), whence also the heat becomes

latent as soon as generated, and the muscle remains cool though acting vigorously, and though the carbon of the effete tissue, entering into union with the oxygen in and around the muscle, is producing an immense quantity of heat.

The *chemical* condition or cause, therefore, of the action of the muscle is the union in it of carbon, etc., with oxygen.

And the *physiological* condition or cause is that current of force sent in upon the muscle which determines that oxidation.

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